TOWARDS IMPROVED TSUNAMI DISASTER RISK REDUCTION – REFLECTIONS FROM THE ANTIPODES

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ABSTRACT

An unusual (double) earthquake event on the 29th September 2009 triggered a region wide tsunami in the central South Pacific. Almost two hundred people lost their lives and wide spread damage occurred to urban systems and the natural environment across several Pacific Island countries. A number of post-tsunami surveys were undertaken in the weeks following the event. We reflect on the experiences and findings of some of these surveys and in particular the UNESCO-IOC International Tsunami Survey Team survey of Samoa undertaken in October 2009. From these various surveys, a number of key lessons emerge regarding how post-tsunami surveys could be undertaken, what theoretical and practical frameworks can be used to improve future tsunami science and risk management.

KEYWORDS: Tsunami, post-tsunami surveys, South Pacific, lessons learned

1. INTRODUCTION

A region-wide tsunami (Fig. 1) in the central South Pacific causing nearly 200 deaths and severe damage to coastal infrastructure in Samoa, American Samoa and Tonga was triggered by an unprecedented earthquake doublet (M_w8.1 and M_w 8.0) at about 17:50:00 UTC on September 29, 2009 (UN OCHA, 2009; Beavan et al., 2010; Lay et al., 2010). The first earthquake of the doublet was located at 15.51^0 S, 172.03^0 W. The second earthquake of the doublet was composed of two sub-events, the first at 15.75^0 S, 172.25^0 W, the second at 16.0^0 S, 172.25^0 W - their combined Moment Magnitude was equivalent to M_w8.0. Whilst death and damage was confined to a limited number of Pacific Island countries (PICs), the tsunami was either observed or recorded on tide gauges across a much wider part of the Pacific.

International Tsunami Survey Teams (ITSTs) are often deployed to conduct rapid post-event assessments (Borrero, 2005; Fritz et al., 2007; McSaveney et al., 2000; Satake et al., 1993). ITSTs have traditionally been composed of experts from single disciplines (e.g., numerical modellers, or geologists, or engineers) interested in gathering data for their particular field of expertise. Most ITSTs have worked according to 'standard' field-survey protocols and some under the structural function and auspices of the United Nations Educational, Scientific and Cultural Organization's Intergovernmental Oceanographic Commission (UNESCO-IOC). For a variety of reasons, there has never been a coordinated, multidisciplinary, multi-sectoral, UNESCO-IOC assessment of the impacts and effects of a tsunami. Further, there have never been any attempts in the immediate aftermath of an event to identify those factors that contributed to the vulnerability and resilience of affected communities and their associated biophysical systems (their 'socio-ecological' systems) despite calls for such approaches (Adger et al., 2005; Calgaro and Lloyd, 2008). This is a pity since the disaster risk reduction (DRR) literature identifies the value that arises from multi-sectoral analyses as part of a 'coupled human-environment

system' (CHES) approach (Adger et al., 2005; Calgaro and Lloyd, 2008; Turner et al., 2003; Huppert and Sparks, 2006; Sieh, 2006) and that in the immediate post-tsunami emergency phase, governments of affected countries urgently require information about the event to better plan short-term response and recovery actions, and enhance their long-term community DRR practice (UN ISDR, 2009). Thus, to date, a great opportunity has been lost.

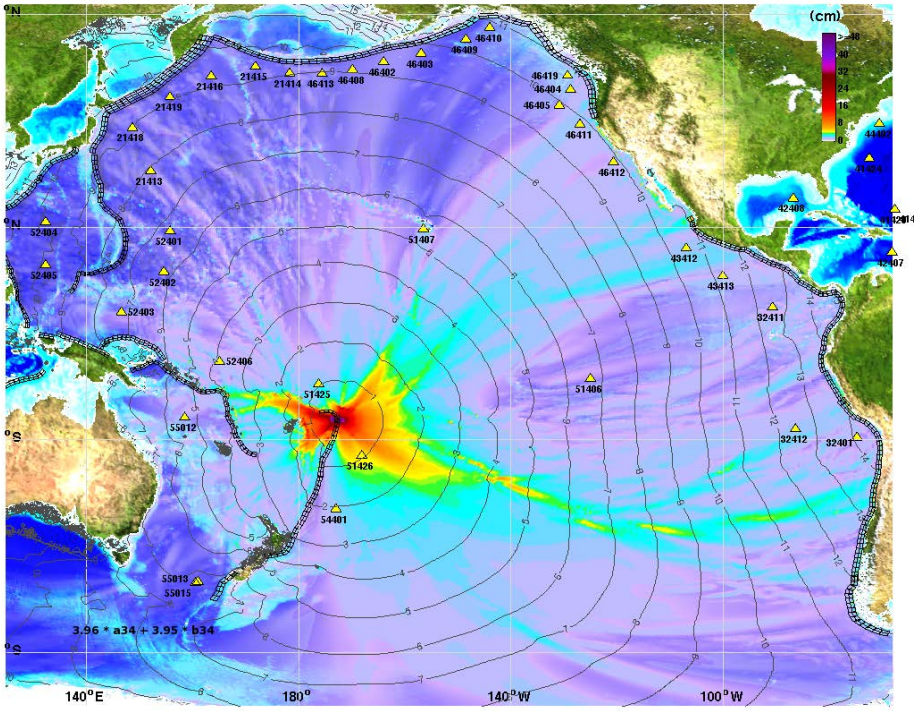

Figure 1: Simulation of the 29th September 2009 South Pacific tsunami by the NOAA Pacific Marine Environmental Lab. The colours relate to the wave amplitude in deep water in cms.

In light of the introduction, the aims of this paper are as follows:

1. To note the number, location, and focus of post-tsunami surveys undertaken in the weeks following the September 2009 South Pacific tsunami;
2. To describe the structure, function and Terms of Reference (ToR) and fundamental research tasks of the UNESCO-IOC ITST Samoa led by the current authors;
3. To examine if the approach taken by the UNESCO-IOC ITST Samoa helped to provided a more detailed explanation for the vulnerability and resilience of the affected coupled human-environment system in Samoa; and
4. To outline the lessons learned from the various post-tsunami surveys generally, and the UNESCO-IOC ITST Samoa experience specifically, and make recommendations for possible future post-tsunami surveys.

2. POST-TSUNAMI SURVEYS AFTER THE SEPTEMBER 2009 SOUTH PACIFIC TSUNAMI

Given that the tsunami had a significant regional effect on PICs, a number of post-tsunami surveys in different PICs were undertaken in the weeks after the tsunami. For a variety of reasons, the majority of teams focused their attention on American Samoa (Fig. 2). Other surveys were conducted on Samoa, Tonga and Wallis and

Futuna (Fig. 2). Here, we provide a summary of surveys for which peer reviewed publications available within the international scientific literature have been produced. In time, there will be further publications from other surveys but they are excluded here since they are not yet publically available.

Table 1 provides a summary of post-tsunami surveys undertaken where peer reviewed publications have arisen. For each survey, the location is provided together with a brief summary of the focus of the survey (as reported by the publishing authors). The reference for the survey publication(s) is also provided. It is clear that all surveys included the classic task of measuring maximum run-up and inundation distances.

Location of survey	**Focus of survey/study**	**References**
Wallis and Futuna	Measurement of run-up heights and inundation distances; eyewitness interviews; analyses of videotape footage and photographs; tsunami hazard assessment	Lamarche et al., 2010
American Samoa	Field measurement of sediment transport; numerical modelling	Apotsos et al., In press
American Samoa, Samoa, Tonga	Inundation, flow depth and run-up measurements; eyewitness accounts	Okal et al., 2010
Samoa	Coral reefs; coral damage; ecosystem functioning	McAdoo et al., In press
Tonga	Measurement of inundation, flow depth and run-up; damage effects in human and environment systems; human knowledge; hazard assessment	Clark et al., In press
American Samoa	Coral reefs; numerical modelling; flow velocities; wave height and inundation distance	Gelfenbaum et al., In press

Table 1: Locations of surveys undertaken after the September 2009 South Pacific tsunami, their focus and publications arising

3. THE UNESCO-IOC INTERNATIONAL TSUNAMI SURVEY TEAM (ITST) SAMOA

3.1 Organisation, Terms of Reference (ToR), structure and function of the UNESCO-IOC ITST Samoa

Given that the tsunami had a significant regional effect, a proposal was made via the International Tsunami Information Center (ITIC) Bulletin Board by the Australian Tsunami Research Centre (ATRC) that an International Tsunami Survey Team (ITST) be established under the framework and structure of UNESCO and its International Oceanographic Commission (IOC) to undertake a technical post-tsunami survey.

Negotiation between the eventual Team Leaders (Dale Dominey-Howes and Randy Thaman – University of the South Pacific), many international scientists of various disciplines, the UNESCO Pacific Regional Office, regional organisations like the Secretariat of Pacific Applied Geoscience Commission (SOPAC), the Secretariat of the Pacific Environment Programme (SPREP), the University of the South Pacific (USP) and the Government of Samoa (GoS), identified a need for and willingness to undertake and actively support, an ITST assessment. From the start, it was agreed that this survey would partner with a regional research organisation - the USP to take account of regional scientific expertise, and with appropriate ministries of the GoS to ensure that (1) incoming international scientists undertook their work in a culturally sensitive and appropriate way and (2)

outputs were relevant to various ministries of the GoS. The guiding principle of the UNESCO-IOC ITST Samoa assessment was to be integrative of different disciplines and skill sets, collaborative between agencies and organisations, and respectful of the culture, practices and needs of the people of Samoa.

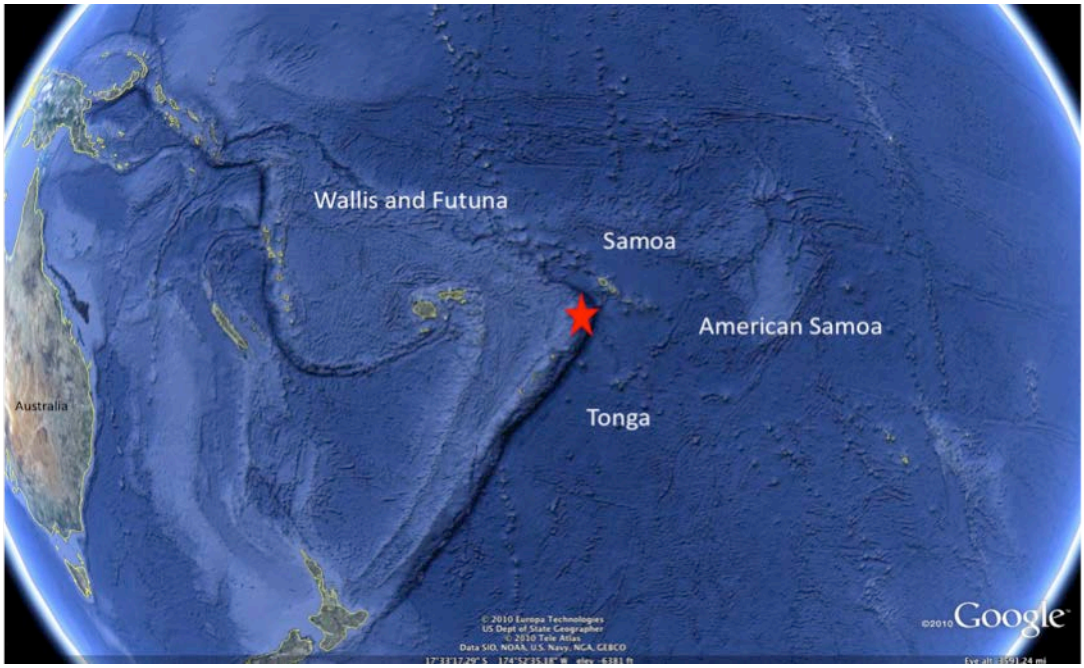

Figure 2: Epicentre (red star) of the tsunamigenic earthquake doublet, places affected by the 2009 tsunami and locations of post-tsunami surveys referred to in Table 1.

To these ends, a 'Terms of Reference' (ToR) for the UNESCO-IOC ITST Samoa were developed and agreed upon by the GoS and the team. The TOR's asked that we undertake the following key tasks:

1. measure maximum inundation and maximum flood run-up. Such measurements are important inputs for running tsunami inundation models;
2. collect geological samples of sediments left by the tsunami. This is so that we may characterise deposits left by the 2009 tsunami. Once completed, we might at a later date, explore the geological record of the coast to identify records of older tsunamis in the recent historic (e.g., the 1917 tsunami) or prehistoric (palaeotsunamis) past. Such work enables geologists to establish longer-term tsunami risk;
3. collect and measure information about environmental and biophysical system impacts of the tsunami on the terrestrial and marine environment in selected locations;
4. measure the type and severity of damage to different types of buildings and record what factors appeared to control damage levels;
5. collect information about survivor experiences and stories through interviews (including for the first time ever in a UNESCO-IOC ITST, video interviews of survivors);
6. collect information on human and community vulnerability and resilience factors at work in different places: i.e., what made a particular community resilient or vulnerable?; and
7. where possible, to map the above information.

The UNESCO-IOC ITST Samoa was structurally divided into 5 sub-groups (Fig. 3) based upon the ToR's set by the GoS and the representative areas of expertise of the volunteer members of the ITST who came from all over

the world. In fact, in the end, the UNESCO-IOC ITST Samoa comprised more than 100 scientists and experts from 16 different countries (Dominey-Howes and Thaman, 2009). On any specific day of the field survey, more than 60 people would be working in the field. The variation in daily numbers reflected the number of local scientists and GoS ministry staff who were available that particular day. These sub-groups, which included members from GoS ministry's, USP, the Scientific Research Organisation of Samoa (SROS), the National University of Samoa (NUS) and non-governmental organisations (NGOs) were:

- Sub-group One – Inundation and Run-up
- Sub-group Two – Building Damage
- Sub-group Three - Social Sciences (including video interviewing)
- Sub-group Four – Geology
- Sub-group Five – Ecosystems and Environment (further divided into Group A Terrestrial and Group B Marine)

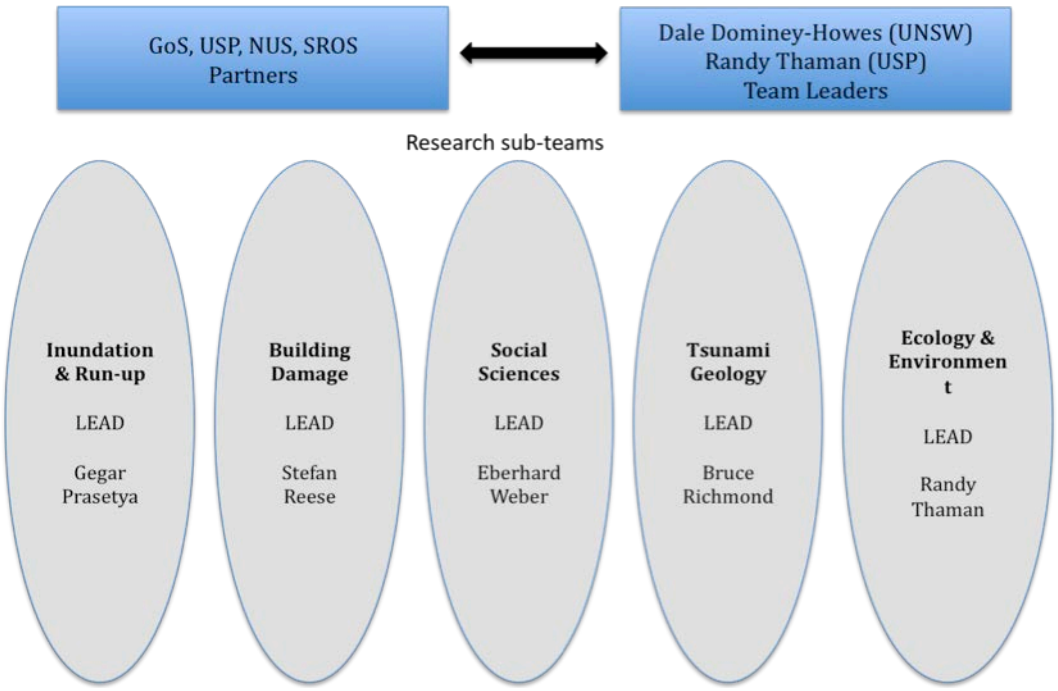

Figure 3: Five sub-groups of the UNESCO-IOC ITST Samoa together with their lead team researcher. The specific research tasks of the sub-groups (teams) mirrored the Terms of Reference set by the Government of Samoa. The whole UNESCO-IOC ITST Samoa was coordinated by Dale Dominey-Howes and Randy Thaman and was a partnership with the host government and regional research organisations.

3.2 Research approach (framework) used by the UNESCO-IOC ITST Samoa - the 'coupled human-environment systems' (CHES) framework

In previous post-tsunami surveys, tsunami experts have tended to work in single discipline fields collecting important (but limited) sets of data. For example, a team may measure run-up and inundation levels; collect geological samples and explore the effects of the tsunami on coastal geomorphology; or investigate the type of damage caused to engineered structures. Whilst we acknowledge these investigations are all very important, they only provide a limited understanding of the impacts and effects of the tsunami. Each discipline field (modelling,

geology, engineering etc) are treated separately. Traditionally, there has been little attempt to integrate these separate fields of study in to a 'statement' about the total impact of the tsunami. There has been even less in the way of attempts to explain the factors that affected the vulnerability and resilience of affected human and environmental systems. This is a great pity because the wider literature within the sustainability science and global environmental change fields has demonstrated that in reality, the world is composed of interrelated and interconnected human and environmental systems (the so called 'coupled human-environment system) and without investigating the relationship between these connected systems, it will be very difficult to develop meaningful tsunami risk management strategies.

Emphasis on the coupled human-environment system acknowledges that humans, as users, actors, and managers of the biophysical environment, are not detached from the physical world in which we live. Instead, we as humans are co-creators of our environment and its evolution over space and time (Schroter, D. *et al*., 2004). Recognising that human activity and biophysical processes are inextricably linked demands that equal attention in sustainability research be given to how society shapes the environment, and how environmental change shapes society (Clark and Dickson, 2003). Vulnerability, from a sustainability science perspective, is also seen as a contextualised characteristic of the coupled-human environment system that is influenced by interactions between biophysical, socio-political, economic, institutional, and technological conditions (Kates *et al*., 2001; Schroter, D. *et al*., 2004).

Seeing vulnerability as a contextualised and multidimensional property of the coupled human-environment system reflects current systems approaches that combine theoretical advances from food security, hazards and climate change research, with those from sustainability science, constructivism, and systems ecology (Turner et al., 2003; Clark et al., 2000; Adger, 2006; Eaking and Luers, 2006; O'Brien, 2006). Inclusive in nature, systems approaches characteristically look at all the components that make up a system, analyse the functionality of each component, and explores the dynamics of their interdependency along with the causal relationships and the feedback consequences of change (Hay, 2006). Focusing on individual components of the social-ecological system does little to explain, or help address, the complexity of multiple interactions within the system and the resultant behaviour of the system as a whole (Clark and Dickson, 2003). .

Vulnerability is place- and system-specific, contextualised, highly scaled, dynamic, and differential. A household's or population's characteristics, the multiple stressors they are vulnerable to, and their capacity to respond and adapt continuously changes over space and time (Adger, 2006; Cannon, 2008; Downing et al., 2006; Smit and Wandel, 2006; Vogel and O'Brien, 2004). These evolutionary changes are determined by three interconnected dimensions of a given location: exposure, sensitivity, and resilience (also referred to as adaptiveness, system adaptiveness and adaptive capacity) (Nelson et al., 2007). Consequently, being vulnerable to a shock or stressor not only means that the exposure unit is both exposed and sensitive to the effects of an event(s), but must also exhibit limited ability to effectively respond and adapt (Polsky et al., 2007).

Resilience refers to the capacity of a system to absorb disturbance and reorganise throughout periods of change whilst retaining function, structure, and identity (Folke, 2006; Walker et al., 2008). The concept closely mirrors vulnerability and shares the same elements; namely the shocks and stressors experienced by the social-ecological system, and the response of and the capacity for the system to cope, reorganise, and adapt without losing function (Moberg, 2008). Resilience however, is more than the flip-side or the absence of vulnerability (IPCC, 2001; Buckle et al., 2000). Vulnerability and resilience are co-constituted and co-exist in the same households, communities, environments, and economies, all of which are in a constant state of flux (Rigg et al., 2008; Scheyvens and Momsen, 2008). Nor is vulnerability or resilience uniform within populations (Fulu, 2007). A household or community is simultaneously vulnerable and resilient, with the degree of each depending upon the type of shock or stress experienced at a given time, and the resources and positive qualities they have at their disposal (pre-and post-event) to counter their vulnerability to that particular shock.

When looking at dynamic social-ecological systems, the whole is more than the sum of its parts and we acknowledge the constructs and processes of resilience and vulnerability cannot be privileged one over the other (Clark and Dickson, 2003; Faulkner and Russell, 1997). In recognizing these complex, interconnected elements of the socio-ecological system, we adopt and modify the basic elements of the various system models already available and synthesise them in to our Fig. 4. This theoretical and practical framework provided us with the template for examining resilience and vulnerability to the tsunami in the place that is called Samoa. We used this framework to guide us as we addressed each of the research tasks/questions outlined in our Terms of Reference.

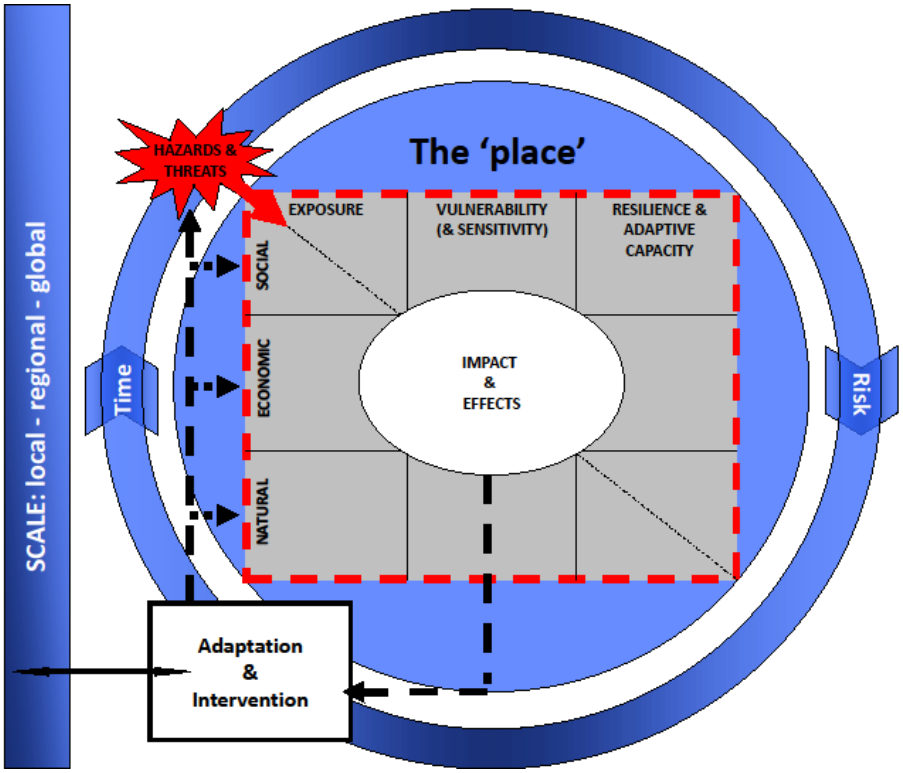

Figure 4: Simplified Coupled Human-Environment System.

3.3 A summary of our findings

It is not our intention to describe in detail here the specific results of the multiple surveys undertaken by the five sub-groups of the UNESCO-IOC ITST Samoa. Such a task would be too long and anyhow, the results are being published elsewhere. However, for the first time, we do present a summary of those factors that appeared to be controlling both vulnerability to and resilience to the tsunami before, during and after the event. Further, we do this for each of the major components of the coupled socio-ecological system. A summary of these factors is shown in Table 2.

BEFORE THE TSUNAMI		
System	**Vulnerability factors**	**Resilience factors**
PHYSICAL		
Inundation and Run-up	Not applicable	Not applicable
Geology & Geomorphology	• Low lying coastal landscape • Narrow width of fringing reef	• Wide reef without breaks
HUMAN		
Human Systems & the Built Environment	• Not understanding previous hazard education materials/efforts • Disbelieving possibility of tsunami occurrence • No cultural memory of past events as reference point • Poor building standards • Poor construction materials • Poor quality workmanship • Lack of knowledge about tsunami effects on buildings • Strong belief that their faith in God and the church will protect them • Location of tourist infrastructure (directly exposed to known hazardous region – Tongan Trench)	• Community had practiced tsunami evacuation • Land tenure structure • Policy and planning of government • Good building codes when enforced Strong social networks including interconnected family, villages and church (faith) networks)
ECOLOGICAL		
Ecosystems & Biodiversity	• Loss of native species • Loss of cultural knowledge of species types and values	• Large trees still present at coast • Mangroves and wetlands etc in original condition
DURING THE TSUNAMI		
System	**Vulnerability factors**	**Resilience factors**
PHYSICAL		
Inundation and Run-up	• Where coastal landscape steep, run-up was high • Where coastal landscape flat, inundation was extensive • Narrow reefs with breaks broken fringing reefs 'focused' tsunami	• Wide, unbroken reefs 'lessened' inundation and run-up • Intact coastal vegetation reduced flow velocity and depth

	inundation/energy • Presence of off-shore islands may have focused inundation at the coast	
Geology & Geomorphology	• Large volumes of soft sediment that may easily be eroded by tsunami • Large quantities of blocky material that may be easily transported (e.g. sea wall) • Wide, unbroken reefs	• Extensive coastal vegetation that holds sediment and soil together reducing erosion
HUMAN		
Human Systems & the Built Environment	• Dependence of some people on hearing a warning message/siren (that may not have occurred), rather than reacting when feeling ground shake • Confusion about how to react • Low mobility of some people to move away from the coast and dependence on others to help • Vulnerability of buildings to damage during tsunami • Short period between earthquake event and tsunami arriving at shore • Large flow depth and high velocity increased vulnerability • Debris in water caused 'impact' damage to buildings • Poor construction style and material and workmanship • Proximity of tourist fales and infrastructure to coast	• Did not wait for a tsunami warning message – just reacted after the tsunami • Had practiced an evacuation • Community warning/helping each other • Good construction design, workmanship and materials • Buildings raised even just 1 metre above surrounding land surface reduced damage levels Vegetation (e.g., trees and mangroves) between the shore and the buildings, on average, increased resilience of buildings
ECOLOGICAL		
Ecosystems & Biodiversity	• As noted in pre-tsunami situation • Debris in backwash of tsunami flow increased damage to corals in shallower water	• As noted in pre-tsunami situation • Ecosystem is adjusted to absorb effects of high energy waves associate with tropical cyclones – so generally resistant
AFTER THE TSUNAMI		
System	**Vulnerability factors**	**Resilience factors**
PHYSICAL		
Inundation and Run-up	Not applicable	Not applicable
Geology &	Not applicable	• Coastal geological

Geomorphology		deposits will remain, meaning we can use deposits as an analogue to examine longer-term records of past tsunamis improving risk assessment • Where erosion occurred (e.g., at beaches), ecosystem is already recovering
HUMAN		
Human Systems & the Built Environment	• Disbelief and shock • Loss of possessions and lack of resources • Interruption to livelihood income • Limited savings • Dependence on aid and family remittances • Uncertainty about the future • Fear of the ocean and ghosts • Time it will take government to complete reconstruction of critical services • Potential impacts of poor health whilst living in temporary accommodation • Lack of knowledge about how to rebuild safely at the coast to protect structures • Not be able to talk about experiences • Buildings are being quickly rebuilt in same areas to same standards as before the tsunami • No chance to implement new design codes/standards Belief that they are being punished by God	• Capability to move further inland • Remittances from family overseas • Strong government support • Close family ties and support • Faith in God and the church • Good work of Red Cross (and other agencies) • Willingness of some businesses to reopen as soon as possible and employ staff again • Talking about experiences helped reduce stress • Knowing that their experiences were being valued so as to provide educational material to other Samoans (and international people) • Many people have capacity to rebuild further inland at higher elevations – outside of likely inundation zone • Local capacity and ability to rebuild with limited resources
ECOLOGICAL		
Ecosystems & Biodiversity	• As identified previously	• Moving inland to higher ground and replanting

	• Not recognising the value of plant (especially, tree) species in providing protection from tsunami inundation • Planting agricultural crop plants that are vulnerable to salt water damage at the coast	coastal areas with trees and other plants • Selecting agricultural plant species that are more tolerant of salt conditions

Table 2: Factors that played (or continue to play) a role in 'vulnerability' and 'resilience' before, during and after the tsunami.

4. LESSONS LEARNED, FUTURE RESEARCH APPROACHES AND NEEDS

The work of the various post-tsunami surveys undertaken after the September 2009 event allow us to learn a series of important lessons. These are discussed in turn.

4.1 Poor understanding of long-term tsunami hazard in the South Pacific

The 2009 South Pacific tsunami was 'modest' in size. Whilst every bit a disaster for those affected by it, it remains from a hazard perspective, 'minor' in relation to the catastrophic 2004 Indian Ocean disaster. However, the event is still very significant because it reminded us that damaging tsunamis do occur in other areas where there has not been much of a historic record of past events. This actually presents a paradox because much work since the 2004 Indian Ocean event means we actually now have a better idea of the long-term (Holocene) frequency and magnitude of Indian Ocean events than we do of Pacific Ocean events though PICs are exposed to tsunamis originating in the near and far field (Fig. 5) (Goff et al., in press a).

What Fig. 5 illustrates is that we actually have a rather poor understanding of the long-term tsunami hazard in the South Pacific – an enormous region of the globe. So, the first lesson is that efforts need to be undertaken to examine and quantify the long-term tsunami hazard for the Pacific Ocean and palaeotsunami studies are a very good way of doing this. Goff et al., (In press a, b) indicate that this is entirely possible.

4.4 Using a 'systems approach' to structuring post-tsunami surveys

Given that the United Nations International Strategy for Disaster Reduction (UN ISDR), the global environmental change and sustainability sciences fields have all recognized that to undertake effective risk reduction strategies, it is necessary to have a sophisticated understanding of both the biophysical world in which hazard events like tsunamis occur and the social world in which disasters unfold – it is time for the tsunami research and risk management communities to embrace these concepts. Using coupled human-environment systems (or socio-ecological) frameworks provide both powerful theoretical and practical frameworks to explore the hard, risk and impacts of tsunamis.

Such efforts – including in post-tsunami survey contexts - should be undertaken in an integrated way with all team members of different discipline fields working together to share their knowledge and expertise. Rather than keeping social scientists, and modellers and geologists separate – putting them together in the same base camp enables cross-fertilisation of knowledge and ideas and an improved understanding of the overall tsunami hazard problem. Fruitful and unexpected ideas and discoveries can emerge when people of different discipline fields who do not normally work together sit and talk and discuss and share. The use of the 'coupled human-environment systems' framework by the UNESCO-IOC ITST Samoa demonstrated that a very detailed understanding of the factors influencing both vulnerability and resilience to the tsunami in the socio-ecological system before, during and after the tsunami could be achieved. This represents a global first.

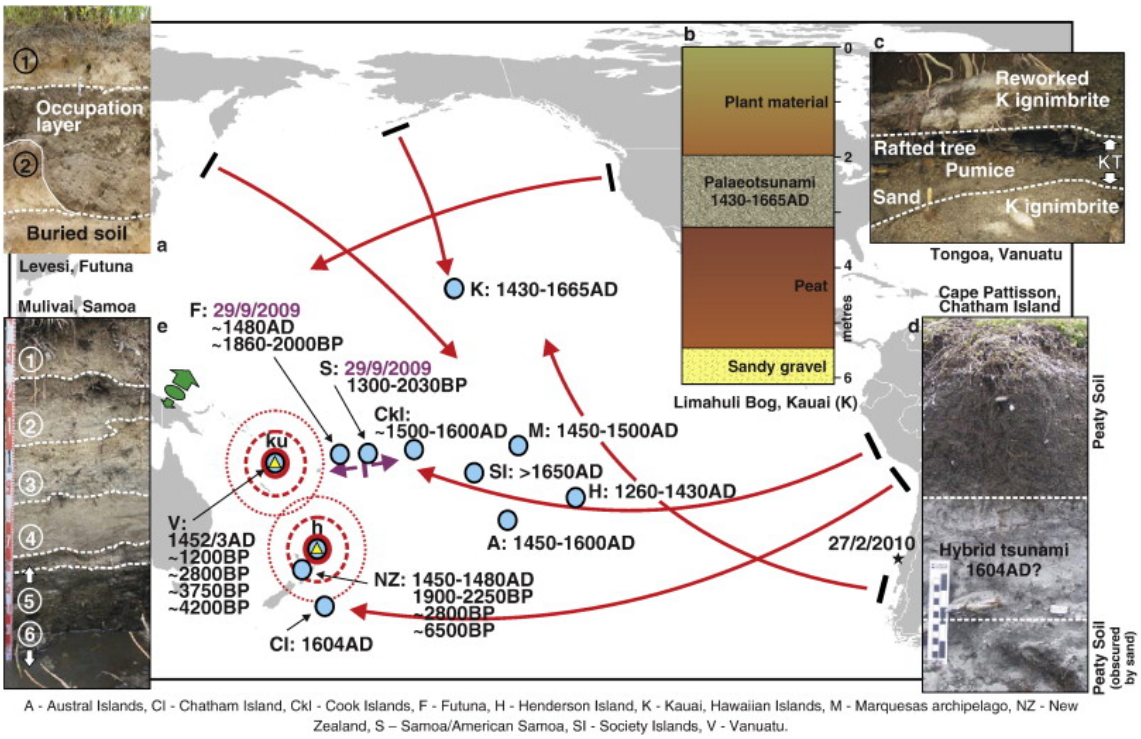

Figure 5: The Pacific Ocean: Examples of local, regional, and distant tsunami sources: green filled oval = local source (earthquake & submarine landslide — Papua New Guinea 1998; yellow filled triangle = regional source (submarine caldera collapse — Kuwae (ku), 1452/1453AD; Healy (h), c.1280–1350AD; purple line = regional source 29 September 2009 South Pacific earthquakes; black lines = regional/distant sources, representative subduction zone segments from various circum-Pacific Ocean country (CPOC) source areas. Approximate travel pathways of tsunami away from source: Green filled arrows — local submarine landslide; red solid, dashed and dotted circles — waning radial pattern for a regional submarine volcano; purple arrows — the regional 29 September South Pacific earthquakes; red arrows — CPOC subduction zones (these are indicative of direction of approximate maximum wave energy in deep water only). Black star marks epicentre of 27 February 2010 Chilean earthquake and the light blue filled black circles show locations of PICs. Photos: **a**, two palaeotsunami deposits at Levesi, Futuna (F); **b**, core log from Kauai (K) with radiocarbon dated (1430–1665 AD) palaeotsunami deposit; **c**, Kuwae eruption tsunami deposit (KT) in Vanuatu (V); **d**, 1604 AD hybrid tsunami on Chatham Island (CI) matching historical 1604 AD Chilean event; **e**, series of six undated sand units and buried soils in trench from Mulivai, Samoa (S) showing potential for identifying palaeotsunamis in the Pacific. Refer to Goff et al., (in press a) for details about individual events.

4.5 Time to revise and update the UNESCO-IOC Post-Tsunami Survey Field Guide

The existing UNECO-IOC Post-tsunami Survey Field Guide is out of date and inadequate for guiding ITSTs in the field. It is limited in its scope of data types that can be gathered, does not adequately account for significant advances in our understanding of tsunami science nor the experiences of numerous post-tsunami surveys undertaken since its publication in 1998. Whilst we recognize this lesson, we do also acknowledge that work has commenced to revise the Field Guide. It will be important that the draft revised Field Guide is circulated for comment and feedback from the wider tsunami scientific community.

4.6 The resilience of Samoa

The September 2009 South Pacific tsunami was a disaster for those affected. However, detailed post-tsunami surveys reveal that in broad terms, both the human and social systems and the biophysical environment were resilient. Pre-tsunami public education activities by the National Disaster Management Office (NDMO) were effective at raising public awareness of the potential tsunami threat when experiencing major coastal earthquakes. 'Proper' response to the ground shaking (i.e., move to higher ground) was not uniform and further work is needed but overall, given the size of the waves and the significant destruction to coastal infrastructure, the relatively low loss of life (in Samoa) is an important lesson to note. Community resilience was relatively high.

It is also clear that the natural environment (in particular the socially and economically important coral reef systems) were rather resilient to damage. Further, what damage did occur is regarded to be temporary and will fully recover within a couple of growth seasons (McAdoo et al., in press). Such observations are important for understanding coastal ecosystem management decision-making.

These observations about the broad resilience of Samoa in the face of the 2009 South Pacific tsunami challenge the assumption that small island developing states are always inherently 'vulnerable'.

5. CONCLUSIONS

A rather unusual earthquake event on the 29th September 2009 triggered a region wide, significant tsunami in the central South Pacific that claimed almost two hundred lives and caused wide spread damage to urban systems and the natural environment across several Pacific Island countries. A number of post-tsunami surveys were undertaken in the weeks following the event and these surveys focused on a range data collection tasks and priorities. Broadly speaking, most post-tsunami surveys are composed of small teams of people with great skill and experience, but limited Terms of Reference in relation to the type of data they collect and measure. Whilst valuable, limited data collection means that in reality, only a partial picture of the tsunami and its impacts and effects will ever emerge. Further, with limited (or no) integration of the various data sets in to a single statement about the nature f the tsunami and the underlying causes of resilience and vulnerability, it is very difficult for governments and relevant experts to make recommendations about long-term disaster risk reduction efforts.

We have reflected on the experiences and findings of some of these surveys and in particular the UNESCO-IOC International Tsunami Survey Team survey of Samoa undertaken in October 2009. From these various surveys, a number of key lessons emerge regarding how post-tsunami surveys could be undertaken, what theoretical and practical frameworks can be used to improve future tsunami science and risk management. We conclude by recommending that a detailed discussion should occur within the wider tsunami scientific and risk management communities about what data is relevant and how that data should be collected and presented.

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